Progress In Electromagnetics Research Letters, Vol. 24, 169–176, 2011

MINIATURIZATION OF BROADBAND 3-DB BRANCH-LINE COUPLER

J. Zhu, Y. Zhou*, and J. Liu

College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China

Abstract—In this letter, a new miniaturized broadband 3-dB branch-line coupler at the center frequency of 880 MHz is proposed. The proposed coupler is designed by means of integrated miniaturization method, which consists of shunt capacitors, fractal geometry and equivalent miniaturized stubs, to achieve 82% size reduction compared with the referenced coupler. The return loss and isolation are both under −20 dB over a 19% relative bandwidth. The proposed coupler is simulated, fabricated and measured. The measured results agree well with the simulated ones.

1. INTRODUCTION

The 3-dB branch-line directional coupler is the fundamental component in planar microwave-integrated circuit and may find numerous applications in microwave system. Operating-bandwidth, flatness and circuit size are important factors to the design. A referenced structure of the broadband 3-dB branch-line coupler in this letter is depicted in Figure 1 and some designs have been given based on this structure [1–3]. A coupler with very flat coupling has been initially presented in [1]. A broadbanding procedure is presented in [2], which improves the operating-bandwidth of a coupler while maintaining agreeable flatness. Tri-band coupler, which is designed by matching networks, has been presented in [3]. However, the referenced couplers at the center frequency of 880 MHz, which based on the structure in Figure 1, occupy about 355 cm^2 on the printed circuit board. The coupler occupies large size so that it is necessary to reduce the circuit size.

Many compact designs have been proposed. Fractal geometry has been presented in [4]. In Figure 2(a), supposing the length of

Received 17 May 2011, Accepted 13 June 2011, Scheduled 16 June 2011
* Corresponding author: Yonggang Zhou (zyg405@nuaa.edu.cn).

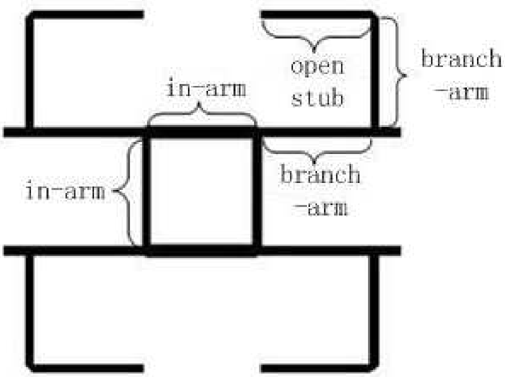

Figure 1. Referenced broadband 3-dB branch-line coupler.

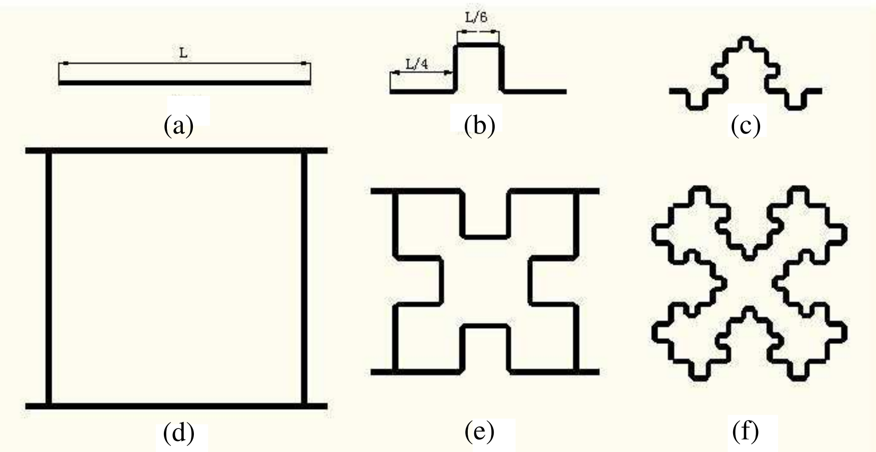

Figure 2. Koch curve in Fractal geometry. (a) Original, (b) 1st iteration order, (c) 2nd iteration order. Coupler with different iteration order, (d) original, (e) 1st iteration order, (f) 2nd iteration order.

the microstrip line is L and width is W. In Figure 2(b), this kind of microstrip line is defined as 1st order iteration Koch curve whose iteration factor is 1/4. This kind of Koch curve is symmetrical. The total length of the microstrip line in Figure 2(b) is $2W + 2L/3$. When $W < L/6$, the microstrip line in Figure 2(b) is shorter than the one in Figure 2(a). The characteristic impedance is unchanged because width is unchanged. Similarly, after 2nd iteration order which iteration factor is 1/4, the total length of the microstrip line in Figure 2(c) is $6W + 4L/9$. Coupler with different iteration order is depicted in Figures 2(d)–2(f).

Lumped-element is widely used to miniaturize the coupler. Distributed capacitor in the inner area has been presented in [5, 6] and miniaturized double-stage 3-dB branch-line coupler is given in these papers. A novel enhanced and miniaturized 90 degree coupler has been presented in [7]. Vertical branches are combined with two shunt capacitors and one series inductor to achieve miniaturization in [7].

Equivalent miniaturized microstrip line presented in [8–10] is to achieve miniaturization, which includes equivalent miniaturized open-stubs, dual-transmission line and T-model approach with open-stubs with high-low impedances.

In this letter, an integrated method of miniaturization has been given to reduce the circuit size of the referenced coupler in Figure 1. The method uses shunt capacitors, fractal geometry and equivalent miniaturized stubs to achieve miniaturization. This new coupler not only occupies smaller size, but also reveals similar circuit performances.

2. COUPLER DESIGN

2.1. Branch-arm Design

Shunt capacitors are used to convert microstrip line of branch-arm in Figure 1 to short high impedance line according to Equation (1).

$$\begin{bmatrix} 0 & jZ_c \\ \frac{j}{Z_c} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ j\omega C_b & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & jZ\sin\theta \\ \frac{j\sin\theta}{Z} & \cos\theta \end{bmatrix} \begin{bmatrix} 1 & 0 \\ j\omega C_b & 1 \end{bmatrix} \tag{1}$$

where Z_c and Z present the impedance of original and equivalent microstrip line respectively, ω is the center frequency and C_b is the shunt capacitor.

It is easy to obtain Equation (2) from Equation (1).

$$C = \frac{\cos\theta}{\omega Z_c}, \quad \theta = \arcsin(Z_c/Z) \tag{2}$$

According to Equation (2), the electric length θ will be reduced when $Z_c < Z$. Then the impedance of the equivalent microstrip line is higher than the impedance of original microstrip line. The length of the equivalent microstrip line will be reduced compared with original one.

The equivalent microstrip line is combined with the Koch curve in Figure 2(b). Structure of microstrip line after combining with shunt capacitors and Koch curve is depicted in Figure 4(c).

2.2. Open-stub Design

Equivalent miniaturized stubs are used to avoid overlapping and achieve miniaturization. Equivalent miniaturized stubs are depicted in Figure 3.

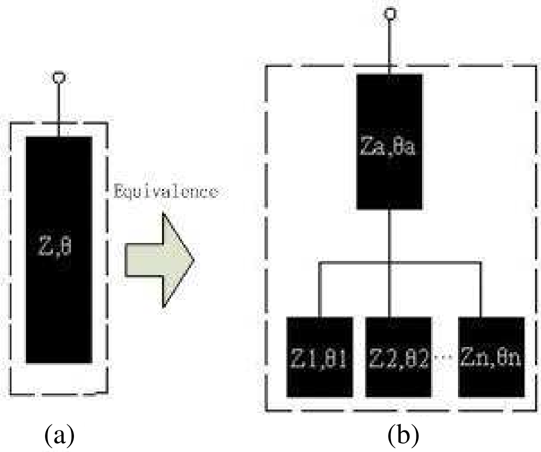

Figure 3. Equivalent miniaturized stubs. (a) Original line. (b) Equivalent miniaturized line.

All the microstrip lines can be accurately calculated by Equation (3).

$$\frac{Z_a \tan\theta - Z\tan\theta_a}{Z_a^2 \tan\theta_a \tan\theta + ZZ_a} = \sum_{i=1}^{n} \frac{\tan\theta_i}{Z_i} \tag{3}$$

where Z and θ stand for the impedance and electric length of the initial open stub (open stub in Figure 1), Z_a and θ_a stand for the impedance and electric length of the feeder line (L_7 in Figure 4(c)), Z_i and θ_i stand for the impedance and electric length of the equivalent miniaturized open stubs (L_6 in Figure 4(b)). n is the number of the shunt open stubs.

If n is higher, the total length of the microstrip line in Figure 3(b) will be shorter than that in Figure 3(a). While in this letter, we choose $n = 3$ to effectively reduce length of open stubs without complex structure.

Tuning stubs have been added (L_5 in Figure 4(b)) to avoid overlapping.

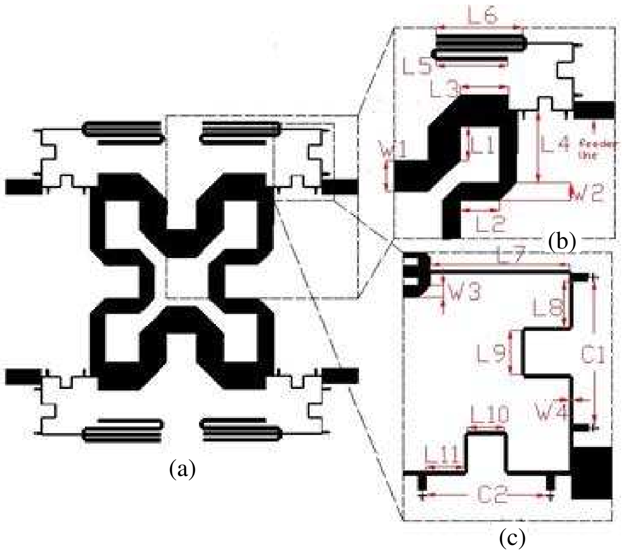

Figure 4. (a) The proposed broadband 3-dB branch-line coupler. (b) (c) Structure of the integrated compact design.

Table 1. (UNIT: mm).

w_1	6.2	l_3	7.6	l_9	2.9
w_2	3.5	l_4	11	l_{10}	2.4
w_3	0.8	l_5	14	l_{11}	2.5
w_4	0.2	l_6	16.8		
l_1	6.6	l_7	9		
l_2	7.5	l_8	3		

2.3. In-arm Design

The miniaturization of the in-arm in Figure 1 microstrip lines is only combined with Koch curve to meet a better matching network. The Koch curve in the in-arm design is 1st iteration order because if W is not much less than L, the coupler in Figure 2(f) may causes complex structure.

2.4. Whole Coupler Design

By using the full wave analysis, we integrate the methods discussed above to miniaturize the coupler and obtain the final structure of the new coupler as depicted in Figure 4(a). The parameters of the fabricated prototype are listed in Table 1. The shunt capacitor of C_1 is 3.3 pF, and C_2 is 2.7 pF.

3. SIMULATION AND EXPERIMENTAL RESULTS

To validate the above design approach, the new miniaturized broadband 3-dB branch-line coupler is fabricated on a substrate with relative dielectric of 3.48, thickness of 1.524 mm and the coupler is depicted in Figure 5. The simulated and measured results are plotted in Figure 6. From Figure 6, we can see agreement between the

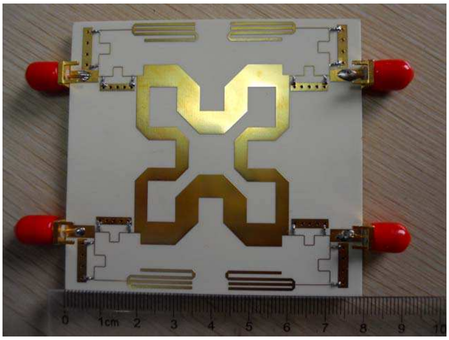

Figure 5. Fabricated broadband 3-dB branch-line coupler.

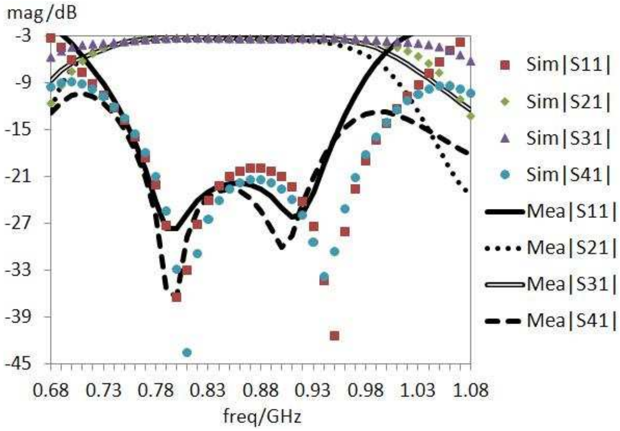

Figure 6. Simulated and measured results of the proposed broadband 3-dB branch-line coupler.

Table 2.

		Area	Band-width	Relative Band-width
Proposed	Simulation	$48.8\,\mathrm{cm}^2$	$780 \sim 960\,\mathrm{MHz}$	20.5%
	Measurement		$768 \sim 938\,\mathrm{MHz}$	19.3%
Referenced	Simulation	$271.6\,\mathrm{cm}^2$	$770 \sim 970\,\mathrm{MHz}$	22.7%

simulation and measurement, except for a little frequency shifting and bandwidth reduction. Frequency shifting and bandwidth reduction may be caused by SMA connectors and weld of chip capacitors. The comparison among the referenced coupler (simulation), simulation of the proposed coupler and measurement of the proposed coupler are given in Table 2. Area is calculated without feeder line. At the center frequency of 880 MHz, $|S_{21}|$ is $-3.5\,\mathrm{dB}$ and $|S_{31}|$ is $-3.8\,\mathrm{dB}$. In the range of bandwidth, the return loss and isolation are both under $-20\,\mathrm{dB}$ in bandwidth, and the flatness of $|S_{21}|$ and $|S_{31}|$ are both under 0.1 dB. Above all, the fabricated coupler only occupies $80\,\mathrm{mm} * 75\,\mathrm{mm}$ on the printed circuit board, achieving up to 82% size reduction compared with the coupler in Figure 1 which work at the center frequency of 880 MHz.

4. CONCLUSION

In this letter, a new miniaturized broadband 3-dB branch-line coupler is proposed. For miniaturization, the shunt capacitors and fractal geometry are used to achieve effective reduction of microstrip line. Similarly, equivalent miniaturized stubs are also adopted to attain size saving of the coupler and avoid microstrip line overlapping. The new coupler has an operating-bandwidth from 768 MHz to 938 MHz and good flatness less than 0.1 dB. The agreement between the simulated and measured results verifies the proposed structure.

ACKNOWLEDGMENT

This work was supported in part by the Open Research Program in China's State Key Laboratory of Millimeter Waves (Grant No. K201103) and in part by the Youth Science and Technology Innovation Funds of Nanjing University of Aeronautics and Astronautics (Grant No. NS20100117).

REFERENCES

1. Riblet, G. P., "A directional coupler with very flat coupling," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 26, No. 2, 70–74, 1978.
2. Mayer, B. and R. Knöchel, "Branch-line couplers with improved design flexibility and broad bandwidth," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 32, 391–394, 1990.
3. Tanigawa, S., K. Hayashi, T. Fujii, T. Kawai, and I. Otha, "Tri-band/broadband matching techniques for 3-dB branch-line couplers," *Proceeding of the 37th European Microwave Conference*, 560–563, 2007.
4. Chen, W. L. and G. M. Wang, "Exact design of novel miniaturised fractal-shaped branch-line couplers using phase-equalising method," *IET Microwaves, Antennas & Propagation*, Vol. 2, No. 8, 773–780, 2007.
5. Jung, S.-C., R. Negra, and F. M. Ghannouchi, "A miniaturized double-stage 3 dB broadband branch-line hybrid coupler using distributed capacitors," *IEEE APMC*, 1323–1326, 2009.
6. Jung, S.-C., R. Negra, and F. M. Ghannouchi, "A Design methodolgy for miniaturized 3-dB branch-line hybrid couplers using distributed capacitors printed in the inner area," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 56, No. 12, 2950–2953, 2008.
7. Shamsinejad, S., M. Soleimani, and N. Komjani, "Novel enhanced and miniaturized 90° coupler for 3G EH mixers," *Progress In Electromagnetics Research Letters*, Vol. 3, 43–50, 2008.
8. Tang, C.-W. and M.-G. Chen, "Synthesizing microstrip branch-line couplers with predetermined compact size and bandwidth," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 55, No. 9, 1926–1934, 2007.
9. Tang, C.-W., M.-G. Chen, and C.-H. Tsai, "Miniaturization of microstrip branch-line coupler with dual transmission lines," *IEEE Microwave and Wireless Components Letters*, Vol. 18, No. 3, 185–187, 2008.
10. Elhiwaris, M. Y. O., S. K. B. A. Rahim, U. A. K. Okonkwo, N. B. M. Jizat, and M. F. Jamlos, "Miniaturized size branch line coupler using open stubs with high-low impedances," *Progress In Electromagnetics Research Letters*, Vol. 23, 65–74, 2011.